

# PACT Stress Testing Protocol

Version 0.3

June 2024

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## 1. Introduction

The purpose of this protocol is to use accelerated stress testing to assess the durability of metal halide perovskite (MHP) photovoltaic (PV) modules. In its current form, the protocol aims to do two things:

- 1) To apply field-relevant stressors to packaged MHP modules to identify early failure mechanisms which can be correlated to field-stressed modules of the same type.
- 2) Provide a minimum recommendation of the accelerated stress testing that may not be captured by existing standards such as IEC 61215.

The current protocol has two test legs. The first is related specifically to the package and is designed to provide a minimum evaluation of the moisture impermeability of the package. A suggested package design is provided on the PACT website; <https://pvfact.sandia.gov/publications-and-protocols/>. The second leg is the metal halide perovskite module specific leg which should only be used when there is reasonable confidence in the reliability of the package.

*Disclaimer: Version 0.3 of this protocol has not been tested or validated against field failures. The initial protocol has been designed with inputs from IEC61215:2021, the MHP ISOS protocols, and input from the community. This protocol will be revised and updated as PACT tests the approach and validates against field data.*

## 2. Definitions and References

- MHP: Metal Halide Perovskite
- PV: Photovoltaic
- IEC 61215:2021: defines requirements for the design qualification and type approval of terrestrial photovoltaic (PV) modules suitable for long-term operation in general open-air climates
- MHP ISOS protocols: “Consensus statement for stability assessment and reporting for perovskite photovoltaics based on ISOS procedures” <https://doi.org/10.1038/s41560-019-0529-5>

## 3. Required equipment

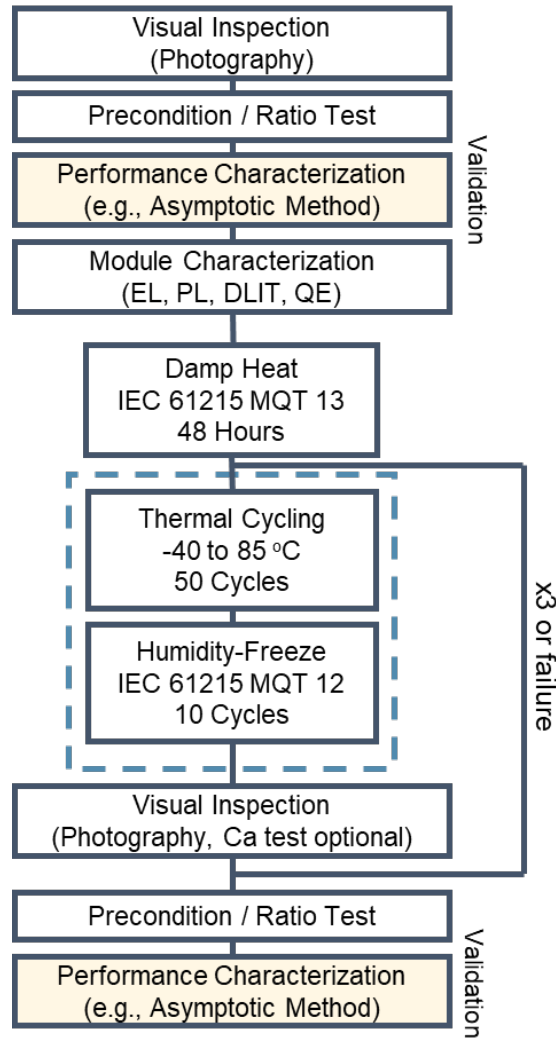
- Full-spectrum light soaking chamber with sample temperature control of  $90 \pm 5$  °C

## 4. Protocol Details

Figure 1 outlines version 0.3 of the accelerated stress testing protocol. Prior to any stress testing it is recommended the modules be characterized by visual inspection, preconditioning/ratio test, and performance characterization. Details of the preconditioning test can be found at <https://pvfact.sandia.gov/publications-and-protocols/>.

The protocol is then divided into two testing legs: MHP-focused and package-focused testing sequences. The package-focused test is a modified test sequence from IEC 63209-1 sequence 3 and is designed to

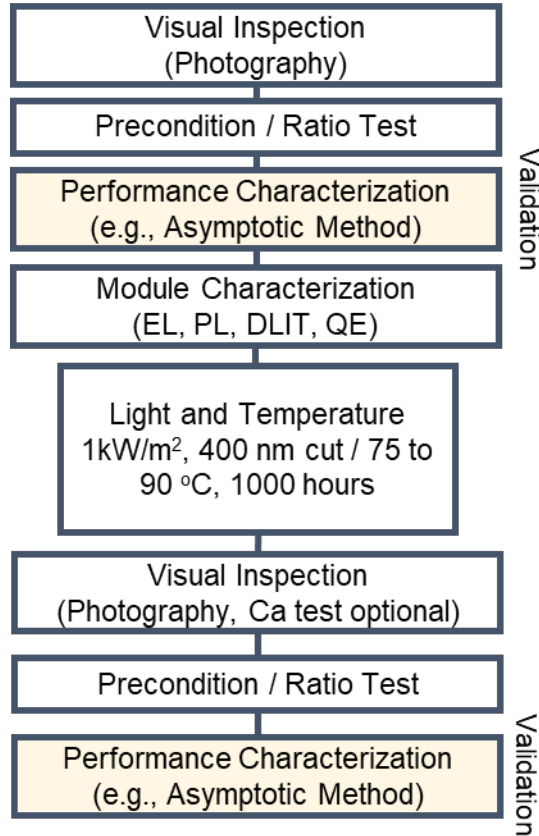
identify package failures such as delamination and moisture ingress. A pass/fail criteria is applicable as defined by IEC 61215-1:2021 clause 8, where no major visual defect is observed. An optional inclusion of calcium evaporated on polyethylene terephthalate substrate inside the package can be used for increased confidence in the moisture impermeability.



**Figure 4-1. Test flow for examination of the package impermeability.**

The MHP-focused test is a supplement to IEC 61215:2021 which is expected to be used in addition to the module qualification tests outlined in the standard. The supplement focuses on light and elevated temperature stress, which is demonstrated to affect the performance of some metal halide perovskites and is not covered by IEC 61215:2021.





**Figure 1-2 Test flow for light and elevated temperature supplement stress test.**

**Light and elevated temperature:** A minimum sample temperature of 75 °C is required at 1-sun for 1000 hours. PV module temperatures can reach 90 °C under certain mounting configurations during outdoor deployment, so it is recommended by PACT that modules are ultimately tested at 90 °C. Temperature should be measured from the rear (non-illuminated) surface of the module. Samples are recommended to be maximum power point tracked during exposure. Light sources that replicate AM1.5 spectrum (with a cut at 400 nm) such as Xenon-arc, Metal-halide or LED are recommended.

## 5. Protocol Validation

This protocol still needs to be validated before it can be adopted more generally and will likely be adjusted as more data is collected. All test parameters and including durations will be optimized against field data collected on sister modules. PACT anticipates updating this document and protocol bi-annually with supporting data and modified procedures.

## 6. Version History

- Version 0.1 – 3/14/2022 – Initial release.

- Version 0.2 – 8/1/2022 – Changed UV testing requirements to specify dose in kWh/m<sup>2</sup> and adjusted module temperature from 60 to 75° C to be in line with Light and Elevated Temperature test.
- Version 0.2.1 – 10/18/2022 – Further adjustments to UV testing requirements to specify dose in the UV range 280 to 400 nm. Additional clarification on the UV spectrum requirements which align with UV preconditioning specifications outlined by IEC 61215:2021 MQT 10.
- Version 0.3 – 4/31/2024 – Leg 2 is now referred to as a supplement to IEC 61215:2021. It is recommended that modules are also tested according to the MQTs outlined in IEC 61215:2021. Updated the light and temperature conditions recommendation to configure modules in MPPT. The light and elevated temperature conditions were updated such that a minimum sample temperature of 75 °C was recommended with an ultimate recommendation for 90 °C.

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